Validation of GOES-R Total Precipitable Water Products Using GPS derived TPW

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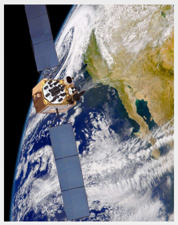
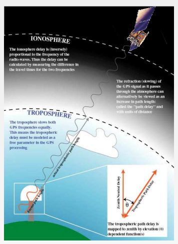
Introduction

Using ground-based Global Positioning System (GPS) receivers to monitor total precipitable water (TPW) in the atmosphere over CONUS is an effective and low cost way to continuously assess GOES-R Sounder Hyper-spectral. Environmental Suite (HES) sensor performance and retrieval accuracy under all weather conditions.

Examples from a collaboration between NOAA Research and NOAA's National Environmental Satellite, and Data Information Service (NESDIS) using data and products from GOES 12, GOES 10 and AIRS data are presented.

Ground-based GPS Meteorology





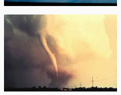
The satellite Global Positioning System (GPS) was developed by the U.S. Military to provide accurate positioning, navigation and timing information anywhere on Earth. GPS is a "dual-use" system, which means that its signals are also available for civilian use free of user fees.

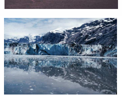
Radio signals transmitted by the constellation of 24-28 GPS satellites in 20,200 km (10,900 nm) high Earth orbits are refracted (i.e. slowed and bent) as they travel from space to receivers at or near the surface of the Earth. Atmospheric refraction is caused by free electrons in the upper atmosphere, and temperature, pressure, and water vapor in the lower atmosphere. The delay or late arrival of the GPS radio signals causes GPS positioning and navigation errors that must be corrected to achieve the highest possible accuracy.

Geodesists developed ways to treat these signal delays as a "nuisance parameter" so they could estimate and remove them to improve survey accuracy. Scientists at NOAA's Earth System Research Laboratory (ESRL) recognized the importance of this work and collaborated with several universities to develop practical ways to use these "nuisance parameters" to continuously monitor water vapor in the troposphere under all weather conditions.

This is one of the best examples we know of **"one persons' signal is another persons' noise."**

Why is this Important?





Water vapor is one of the most important constituents of the atmosphere since it is the means by which moisture and latent heat are transported to cause "weather". Water vapor is also a greenhouse gas that plays a critical role in the global climate system. This role is not restricted to absorbing and radiating energy from the sun, but includes the effect it has on the formation of clouds and aerosols and the chemistry of the lower atmosphere.

Despite its importance to atmospheric processes over a wide range of spatial and temporal scales, water vapor is still one of the least understood and poorly described components of the Earth's atmosphere. A major reason for this is the lack of timely and accurate water vapor observations under all weather conditions. Water vapor has high temporal and spatial variability, and its distribution can change rapidly, especially under active weather conditions.

The more we rely on satellite observations to provide information about water vapor variability for weather forecasting, climate monitoring and research, the greater is our need for independent observation verification and validation.

As technology advances, and new ways of making measurements are developed or made more economical, it becomes feasible to make comparative measurements of the same parameters using totally independent techniques. One such technique is Ground-based GPS Meteorology.

Our goal is to make water vapor information derived from GOES-R as accurate and reliable as possible under all weather conditions. How we propose to do this is the subject of this poster presentation.

Validation of GOES 12 & 10 TPW Products

As part of ESRL's contribution to the International H2O experiment (IHOP-2002) that was carried out May 25-Jun 15, 2002 in the U.S. Southern Great Plains, we used GPS observations to verify hourly GOES TPW products derived from GOES 12 Sounder radiances.

We started by comparing half-hourly GPS TPW measurements with 3-h radiosonde measurements made at 5 U.S. Department of Energy Atmospheric Radiation Measurement (ARM) sites in the area, and twice-daily measurements made at the NWS Upper-Air site in Norman, OK (**Figure 1**).

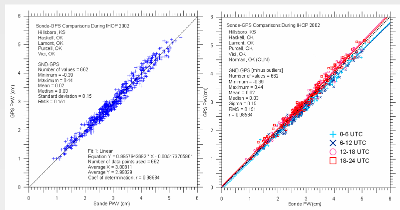


Fig 1. Scatter plots showing comparisons between GPS and Radiosondes (left), and comparisons binned by time-of day (right) during IHOP-2002. A small (< 1.5 mm) day-night bias was discovered, with sondes wetter than GPS at night and dryer than GPS during the day.

These comparisons defined an objective reference for subsequent comparisons of temporally matched GPS and GOES 12 moisture retrievals made at the sites identified above. The results (**Figure 2**) were unexpected since they showed a strong diurnal periodicity that agreed best (i.e. smallest differences) at synoptic (0 UTC and 12 UTC) times. Until this experiment, there were no known comparisons of GOES TPW and other observations made around the clock. This was our first clue that the estimated errors associated with the GOES 12 TPW product might not be representative of the errors at all hours of the day.

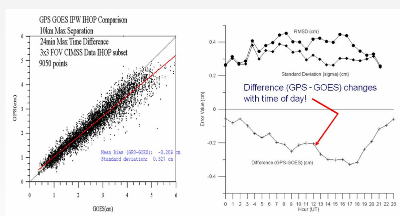


Fig 2. Asynoptic variability of GOES moisture product data when differenced against GPS IPW data at co-located sites during IHOP 2002.

Extension of the Work to Include GOES 10

In summer 2005, we expanded the domain to include the entire CONUS Region (**Figure 3**) and included GOES-10 TPW products for the first time.

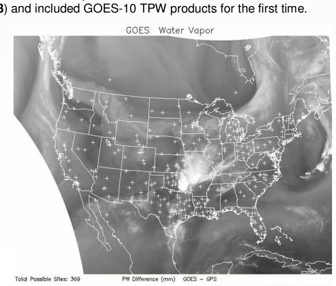


Fig 3. CONUS region showing the location of GPS sites (white crosses) used to validate GOES 12 and GOES 10 TPW products.

Validation of GOES 12 & 10 TPW Products (continued)

Once again, we were surprised to find that GOES 10 and GOES 12 comparisons have very different characteristics (**Figure 4**). Note that GOES 10 minus GPS biases and RMS differences are consistently smaller than GOES 12 over the same period.

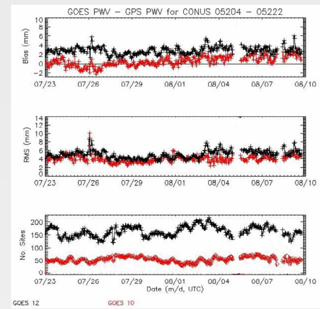


Fig 4. GOES 10 and GOES 12 TPW comparisons with GPS over CONUS. The fewer number of GOES 10 comparisons (averaging 50/hr) than GOES 12 (averaging 150/hr) is primarily a reflection of the asymmetric distribution of GPS-Met sites over CONUS. There are currently 3x more sites east of the Rocky Mountains than west.

Histograms of the various differences between GOES 10 and 12 (**Figure 5**) can be useful when assessing the overall performance of the retrieval process. Here we see that for some reason GOES 12 has more outliers than GOES 10. Furthermore, even though the GOES 10 data set is the smaller, the overall spread of the data shows a narrower character in keeping with the lower difference RMS values observed.

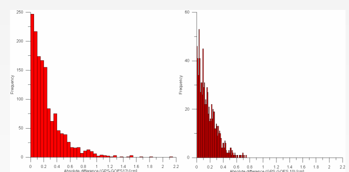


Fig 5. Histograms of the differences between GPS TPW and GOES 12 and 10 products on the same day. Note the tendency for GOES 12 to have a larger number of outliers greater than 8 mm than GOES 10.

The cause of the behavior exhibited above can be clearly seen in the infrared GOES image composite in **Figure 6**. Comparisons east of the Texas-New Mexico boarder are usually made with GOES 12 and are usually wetter (green and blue colors) than the comparisons west of the New Mexico-Arizona boarder which are made primarily with GOES 10 (white and tan colors). Attention is drawn to the exceptionally large wet biases in Eastern Texas and Western Louisiana.

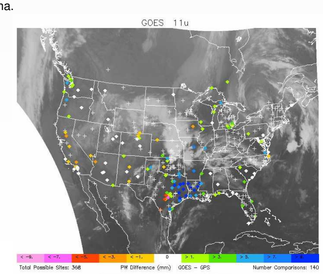


Fig 6. GOES infrared composite image of CONUS illustrating the tendency for GOES 12 TPW comparisons in the Eastern U.S. to be biased wet compared with than those made with GOES 10 in the West.

Using GPS to Validate GOES-R HES Data

Based on these studies, we propose the use the evolving network of ground-based GPS receivers as part of the system to continuously monitor TPW over land under all weather conditions. ***We believe that this will be an effective and low cost way to monitor and assess GOES-R Hyperspectral Environmental Suite (HES) long-term sensor performance and retrieval accuracy.*** The strategy will combine the one described in this poster with validation techniques that proved successful in AIRS studies conducted by several of the co-authors. In this approach, GPS is used to bias-correct radiosonde moisture soundings, and then the radiances derived from the corrected RAOB soundings were compared with radiances observed by the Atmospheric Infrared Sounder (AIRS) radiometer on the NASA Aqua Spacecraft.

Through the Integrated Earth Observing System/Global Earth Observing System of Systems (IEOS/GEOSS) we hope to expand the GPS-Met network to cover most of North and South America. The temporal resolution of GPS total water vapor measurements combined with the potentially large number of GPS receivers and the spatial and temporal resolution of the GOES-R observations will allow us to form a large number of coincident GOES-R HES-GPS TPW pairs. The robust statistical comparison of GOES-R HES and GPS TPW pairs will be used to validate the GOES-R HES water vapor data and retrieval process.

Results & Recommendations

- This study has resulted in changes in the operational data processing algorithms used to create the GOES TPW products. ***Diurnal variations have been all but eliminated***, and improvements in cloud detection have ***reduced the differences between GOES and GPS by almost 50%*** since the start of the project!
- Uncertainties about the causes of the differences remain. What is clear is that the differences between GPS and GOES in the winter are smaller in the cold months than in the warm months, and that the differences between GPS & GOES 10 are always smaller than the differences with GOES 12.
- A key to resolving many of these problems or uncertainties prior to the launch of GOES-R is ***improved quality control***.
- Product generation could be extended to look at the time-series continuity of the GOES product. Sudden departures from an otherwise steady trend could be used to flag additional QC examination for the retrieval in question. As we have noted many outliers occur abruptly rather than in a gradual trend. However, gradual departures worsening with time have been observed, they are far out numbered by the sudden, abrupt moistening or drying of a retrieval product.
- Additional QC might include an examination of neighboring model moisture values to identify situations where there is a sudden moist (or dry) gradient in the vicinity of the retrieval. Thus, a relevant rapid change in moisture might well be warranted, and this might be corroborated by the adjacent model moisture field. It might be that the model has the gradient in the incorrect location, and this is being better tracked by GOES-R. If the nearby moisture field was otherwise assumed to be fairly static, than the retrieval might really be called into question.
- Improved cloud identification will help in the retrieval process. We would anticipate that GOES-R will have better capability to discern the cloud situation at a single field of view and this might go a long way to improving the product. We have seen a few cases this spring where there exist low warm clouds that are fairly uniform in nature that are only apparent in daytime visible images of clouds. IR detects the field as being uniformly warm and nearly the same skin temperature of the nearby clear areas. The current GOES product should explore ways to improve low-cloud detection.
- Comparing retrievals in overlapping regions performed by GOES 10 and GOES 12 have shown that more times than not, GOES 12 is more moist. This would indicate that the filter response function or some factor in forward modeling of the GOES radiance used in the retrieval processing is incorrect and causes a moist bias in GOES 12. Data suggest that it might be worthwhile to revisit the elements that enter the forward radiance model computations for retrieval generation.